

## §6. Simulation of Alfvén Eigenmodes and Energetic Particles in an LHD Plasma

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The interesting experimental results of Alfvén eigenmodes in the LHD and CHS plasmas motivated us to extend the MEGA code<sup>1,2)</sup> for helical plasmas. In the MEGA code, the MHD equations are coupled with the energetic ions through the energetic ion perpendicular current. The MEGA code has been extended to the helical coordinate system  $(u^1, u^2, u^3)$ <sup>3)</sup> which is used in the MHD equilibrium code, HINT. Relations between the helical coordinates and the cylindrical coordinates  $(R, \varphi, z)$  for LHD are

$$h = -1/2,$$

$$M = 10,$$

$$R = R_0 + u^1 \cos(hMu^3) + u^2 \sin(hMu^3),$$

$$z = -[u^1 \sin(hMu^3) - u^2 \cos(hMu^3)],$$

$$\varphi = -u^3.$$

The vector calculations are expressed using the metric tensor as follows:

$$(\nabla \phi)^i = g^{ij} \frac{\partial}{\partial x^j} \phi,$$

$$\nabla \cdot \mathbf{v} = \frac{1}{\sqrt{g}} \frac{\partial}{\partial x^j} \sqrt{g} v^j,$$

$$\mathbf{j} \cdot \mathbf{E} = g_{ij} j^i E^j,$$

$$(\mathbf{j} \times \mathbf{B})^i = \sqrt{g} g^{ij} e_{jkl} j^k B^l,$$

$$(\nabla \times \mathbf{B})^i = \frac{1}{\sqrt{g}} e^{ijk} \frac{\partial}{\partial x^j} g_{kl} B^l.$$

The numerical methods are the 4th order finite difference for the MHD equations and the 4th order Runge-Kutta method for the time integration. The numbers of grid points are (91, 115, 1000) for  $(u_1, u_2, u_3)$  coordinates. The  $\mathcal{O}$  particle simulation is applied to the energetic ions. The number of marker particles is  $N=4 \times 10^6$ .

The MHD equilibrium of the LHD plasma was calculated using the HINT code. The rotational transform and the pressure in the equilibrium are shown in the left panel of Fig.1. The Alfvén continuous spectra for the toroidal mode number  $n=2$  are shown in the right panel of Fig. 1. An example of passing particle orbit is shown in Fig. 2. In this calculation, the magnetic field intensity is  $B=1.5\text{T}$ , the energy of the particle is  $E=150\text{keV}$ , the major radius is  $R_0=3.75\text{m}$ , and the rotational transform is  $\iota/2\pi=0.35$  at the plasma center. We see that the envelope of the particle trajectory is closed in the left panel of Fig. 2, which suggests a good particle confinement although the effects of the helical field are seen in both the panels of Fig. 2.

Alfvén eigenmodes were investigated in the LHD plasma. The beam ions with high beta value  $\beta_{h/0}=P_{h/0}/(B^2/2\mu_0)=3.9\%$  are employed to destabilize Alfvén

eigenmodes. The beam ions have only the parallel velocity. A toroidal Alfvén eigenmode (TAE) with  $n=2$  is destabilized. The real frequency and the growth rate are  $\omega/\omega_A \sim 0.31$ ,  $\gamma/\omega_A \sim 0.028$ , respectively. The time evolution of a radial velocity harmonic with  $m/n=4/2$  and the spatial profile of the TAE are shown in Fig. 3.

The high  $\beta_{h/0}$ , 3.9% is needed to destabilize the TAE. We can attribute the stability of the TAE to the narrow gap of the Alfvén continuous spectra shown in the right panel of Fig. 1. The narrow gap enhances the continuum damping and the stability of TAEs. It would be interesting to investigate the LHD plasmas with low magnetic shear where the continuum damping is not effective.

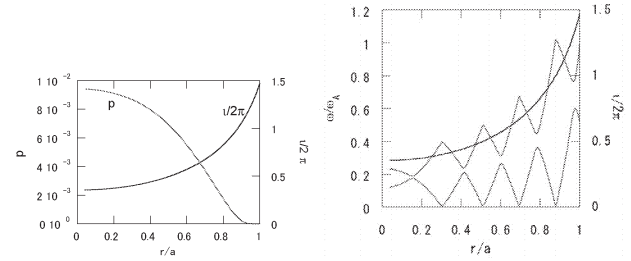


Fig. 1. Rotational transform and pressure in the LHD equilibrium (left panel) and Alfvén continuous spectra for the toroidal mode number  $n=2$  (right panel).

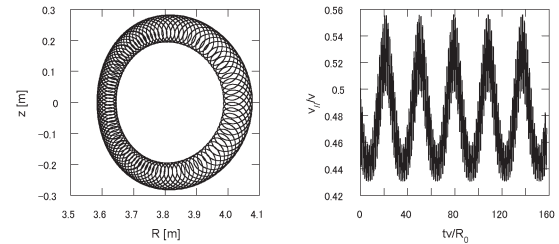


Fig. 2. An example of passing particle orbit. In this calculation, the magnetic field intensity is  $B=1.5\text{T}$ , the energy of the particle is  $E=150\text{keV}$ , the major radius is  $R_0=3.75\text{m}$ , and the rotational transform is  $\iota/2\pi=0.35$  at the plasma center.

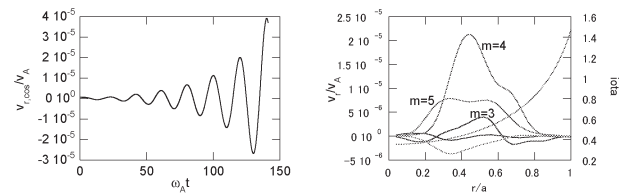


Fig. 3. Time evolution of a radial velocity harmonic with  $m/n=4/2$  (left panel) and spatial profile of the TAE destabilized by the beam ions (right panel).

### References

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- 2) Todo, Y. et al., Phys. Plasmas **12**, 012503 (2005).
- 3) Todo, Y. et al., in Fusion Energy 2004 (Proc. 20th Int. Conf. Vilamoura, 2004) IAEA, Vienna, TH/3-1Ra.